An

Initial Study

of the

Fundamentals of Ice Crystal Icing Physics

in the

NASA Propulsion Systems Laboratory

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Outline

- Introduction & background
- NASA Fundamental Ice Crystal Icing Research Goals
  - Concepts using the NASA Propulsion System Laboratory (PSL)
- Experimental Description
- Results
  - Freeze-out characteristics of cloud
  - Changes in aero-thermal conditions at the test section
  - Accreted ice characteristics observed
- Summary

Introduction

- NASA investigating the fundamental physics of ice crystal icing (ICI)
- Challenging to study ice-accretion physics directly inside the engine
  - Trying to simulate local ICI environment without using an engine
- This paper presents an initial study of the fundamental physics of ICI using PSL
  - Test occurred in March 2016
  - Select results presented
    - Last year, presented preliminary work in preparation for this test
  - Complementary papers to follow

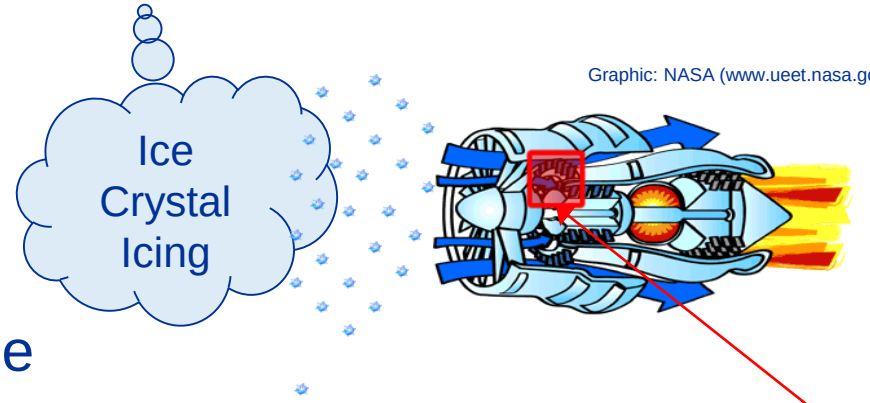
Advance Air Transport Technology Project (AATT; 2015 +)
Advanced Aircraft Icing (AAI) Subproject

Technical Challenge:
Expand engine aero-thermodynamic modeling capability to predictively assess the onset of icing in current and N+2/N+3 aircraft during flight operation (FY21).

The simulation tools are well anchored in results from both fundamental physics studies and full engine tests.

NASA Fundamental ICI Research Goals

- Identify and bound the conditions affecting ice-crystal ice accretion at the (local) accretion site
- Generate & characterize (i.e. measure) those conditions
- Gather data and develop models on ice-crystal icing factors

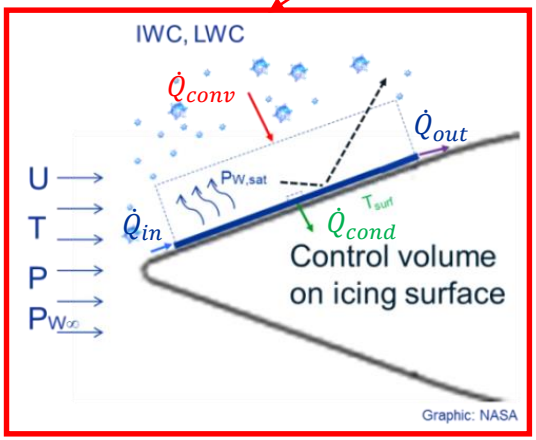


Graphic: NASA (www.ueet.nasa.gov)

Engine Tests

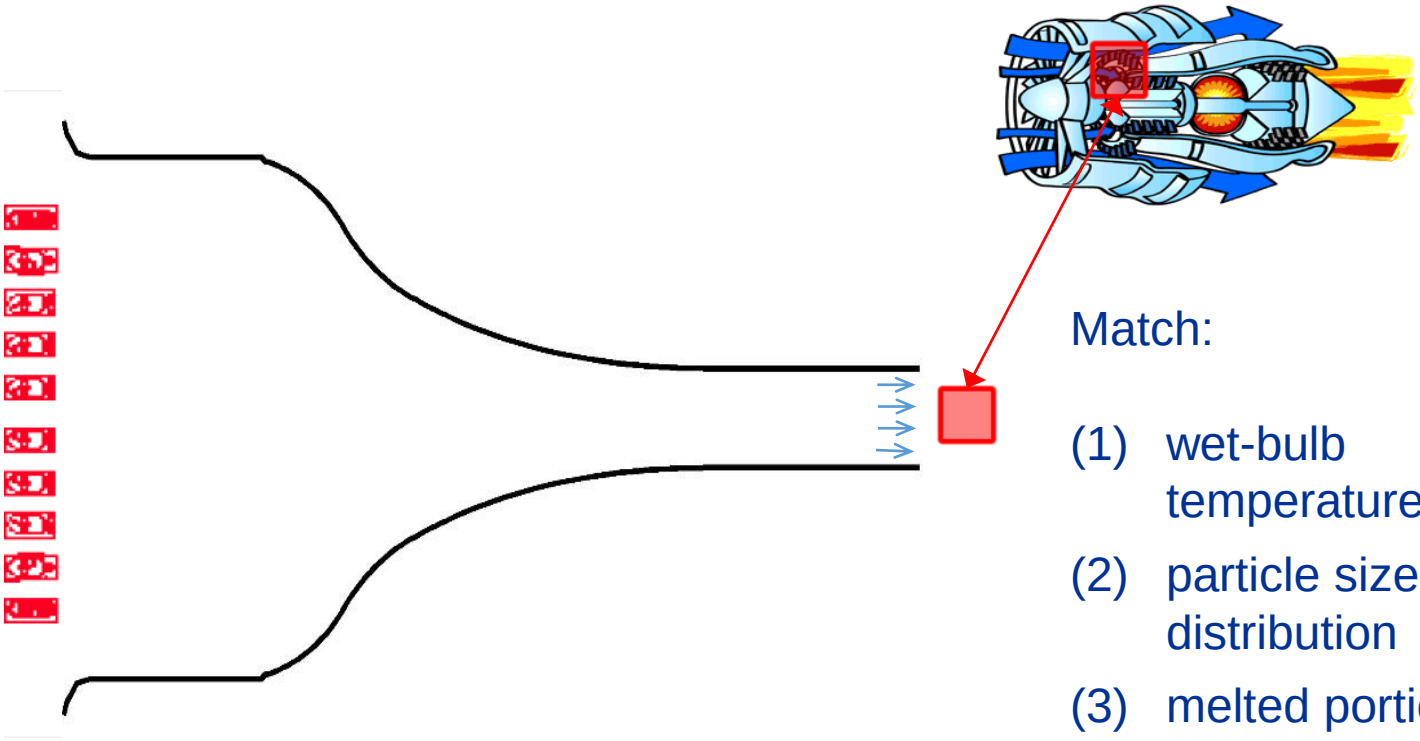
Link actual conditions in an engine to fundamental work

Local Region



Local region requires more information than full-scale test (e.g. melt ratio)

Concept Using PSL



Match:

(1) wet-bulb temperature

(2) particle size distribution

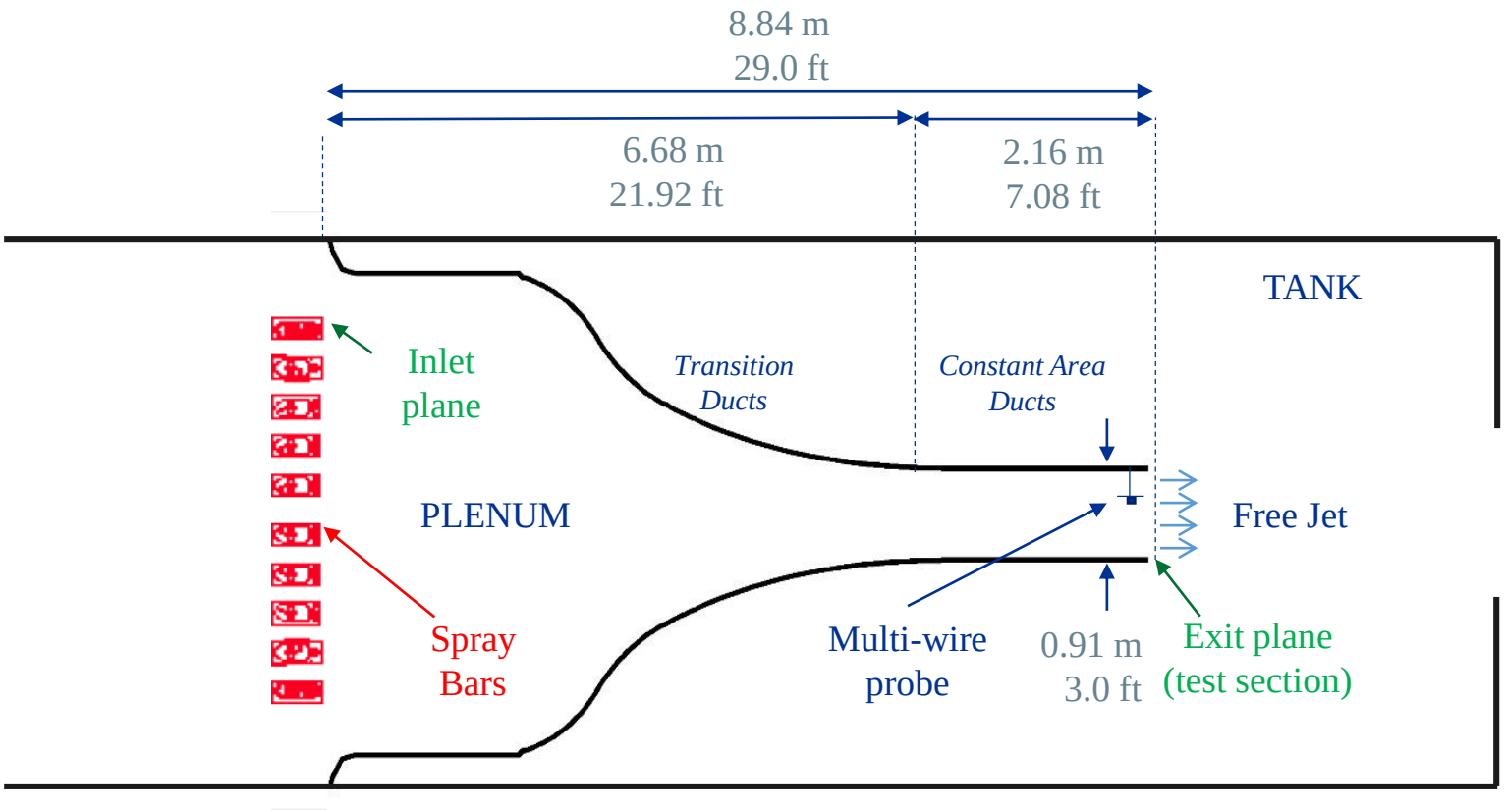
(3) melted portion of incoming ice

Goal: Ability to generate a prescribed mixed-phase condition at the test section for fundamental ice-crystal icing research

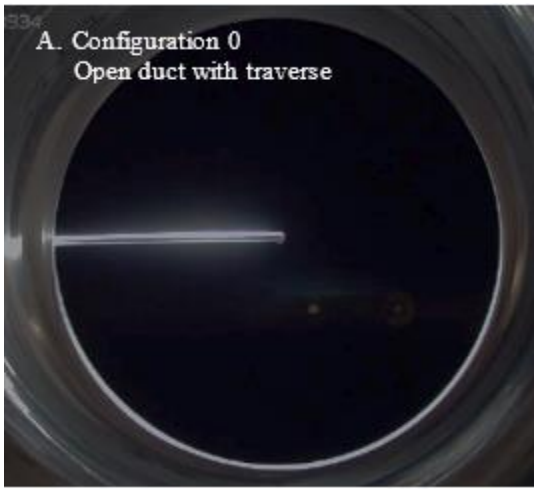
Fundamental Test #1

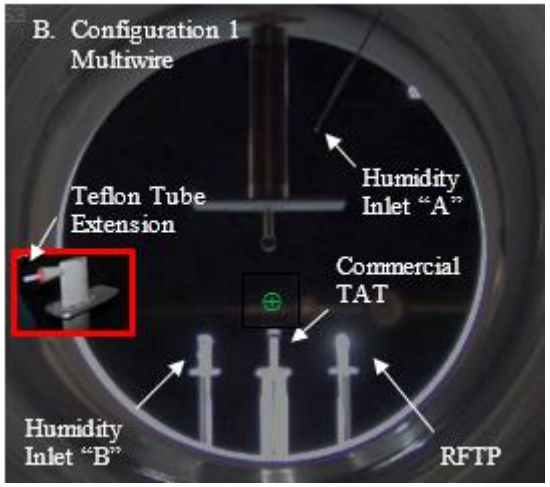
- **Eight (8) days of testing occurred in March 2016**
- **Objectives**
  - Examine spray bar and plenum parameters and how they affect the mixed-phase at the exit of the free jet
  - Cloud characterization at the test section:
    - Melt ratio (fraction of freeze out)
    - Total water content
    - Temperature & humidity measurements at test section (cloud on vs. cloud off)
    - Particle size distributions
    - Uniformity
  - Observe ice accretion

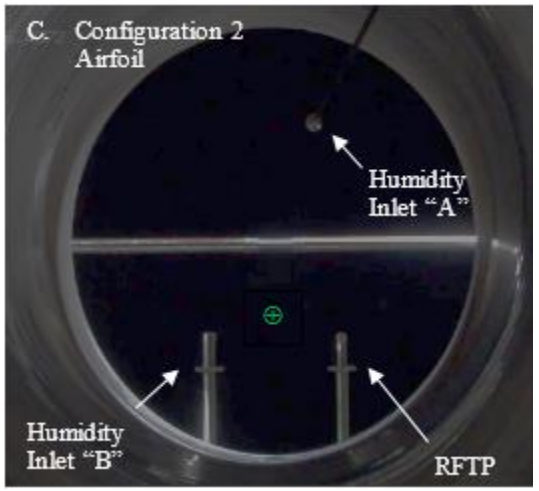
PSL Configuration

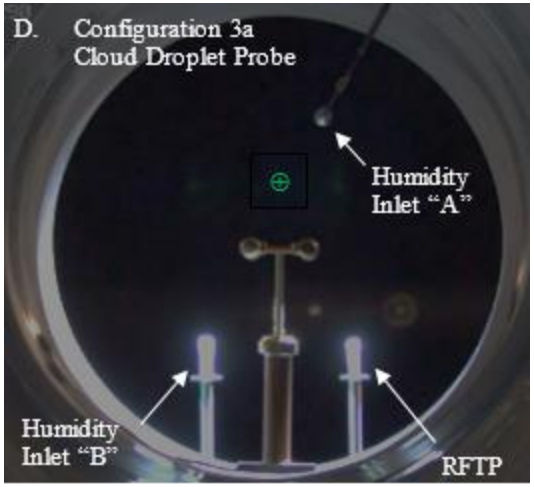


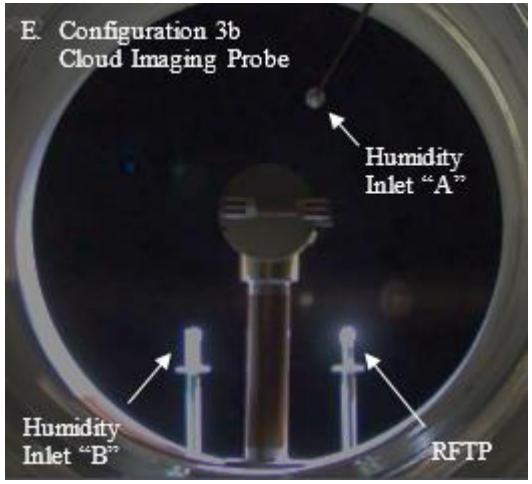
Test Configurations

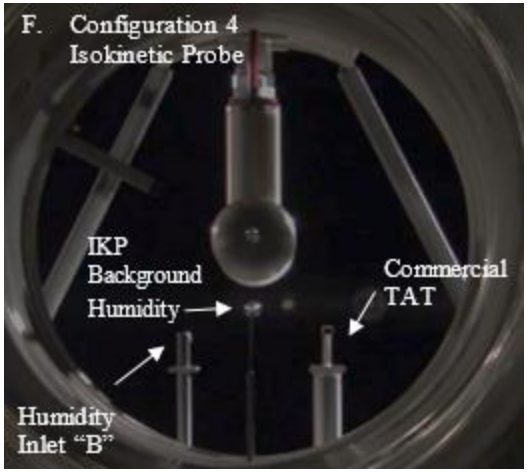








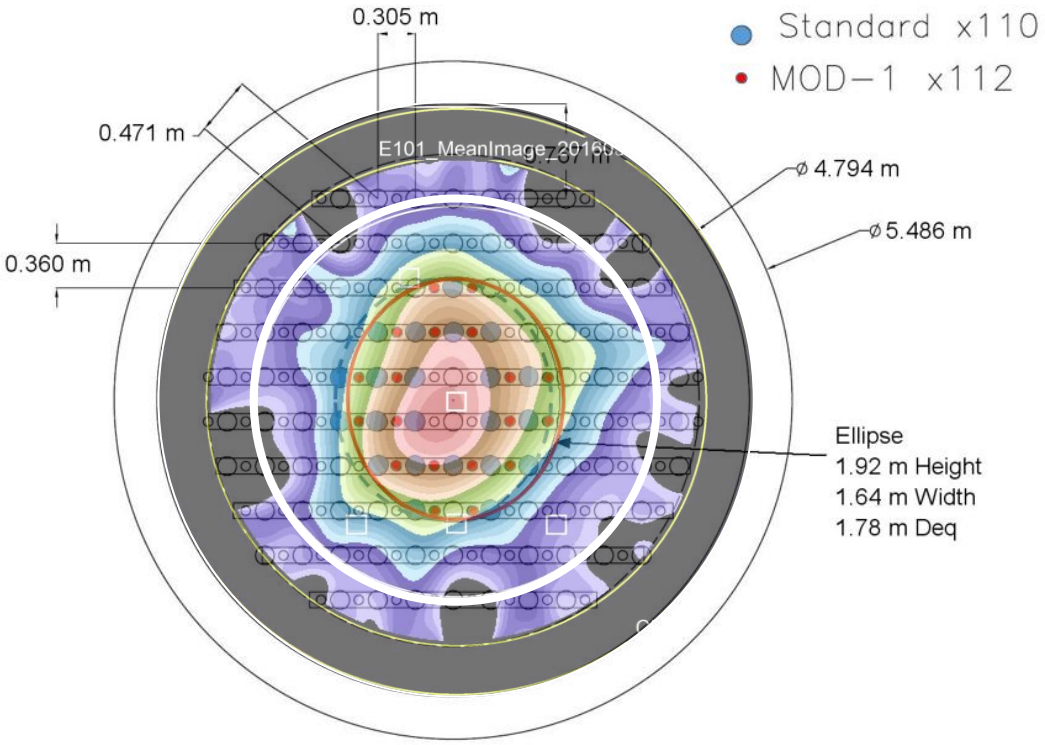




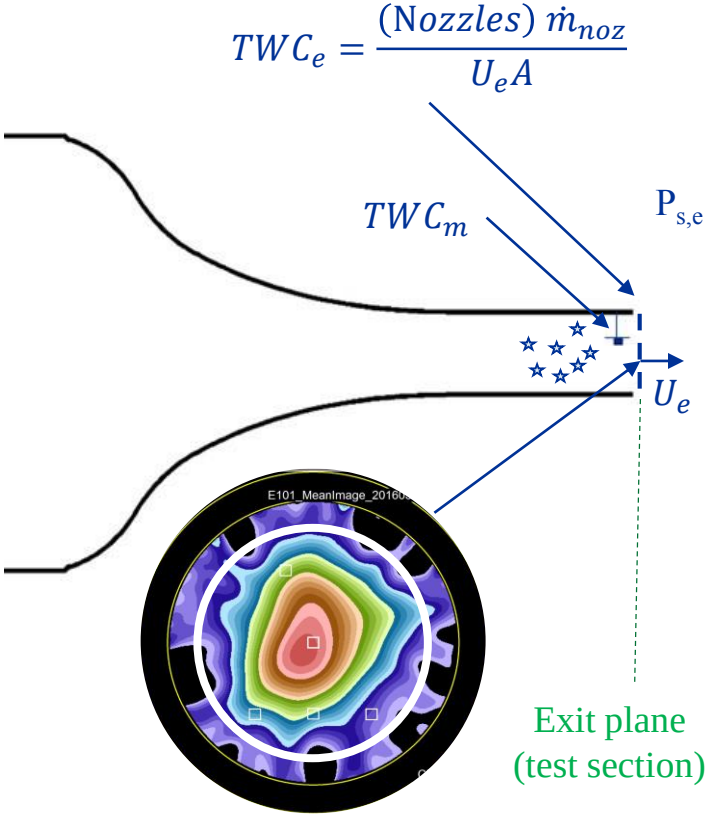
Mixed-Phase Investigation

Plenum Relative Humidity Sweep Approach

Parameters



Nomenclature

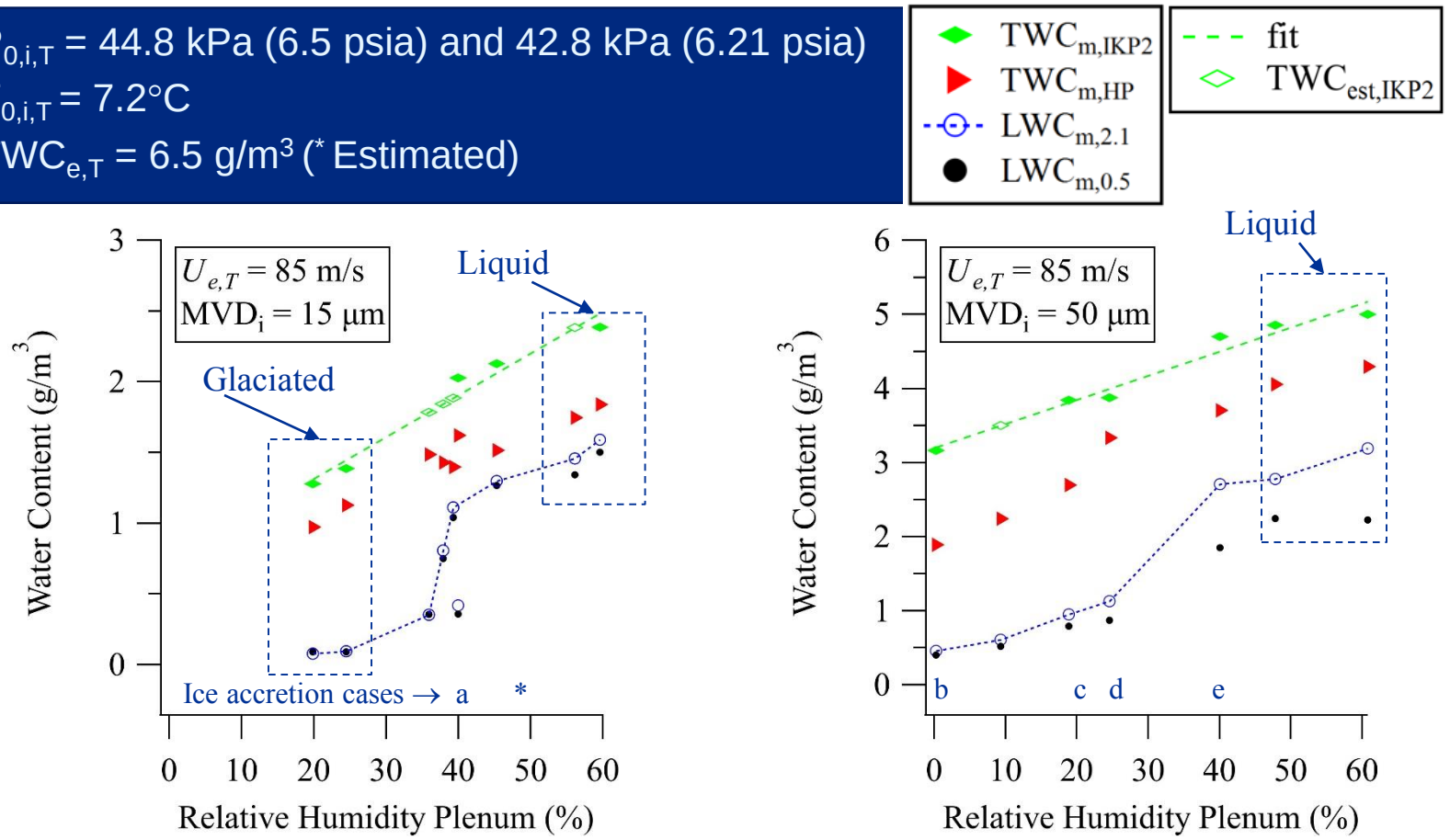


Mixed-Phase Investigation

Plenum Relative Humidity Sweep Results

Water Content Measurement Results

$P_{0,i,T}$ = 44.8 kPa (6.5 psia) and 42.8 kPa (6.21 psia)
$T_{0,i,T}$ = 7.2°C
$TWC_{e,T}$ = 6.5 g/m^3 (* Estimated)



Mixed-Phase Investigation

Plenum Relative Humidity Sweep Results

Test Section T_{wb} (static) and Melt Ratio

$P_{0,i,T}$ = 44.8 kPa (6.5 psia) and 42.8 kPa (6.21 psia)
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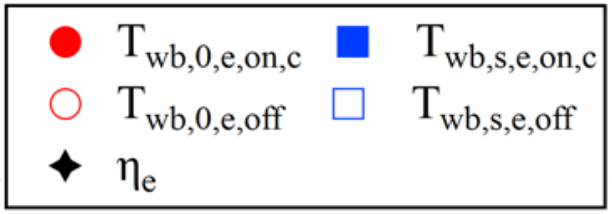
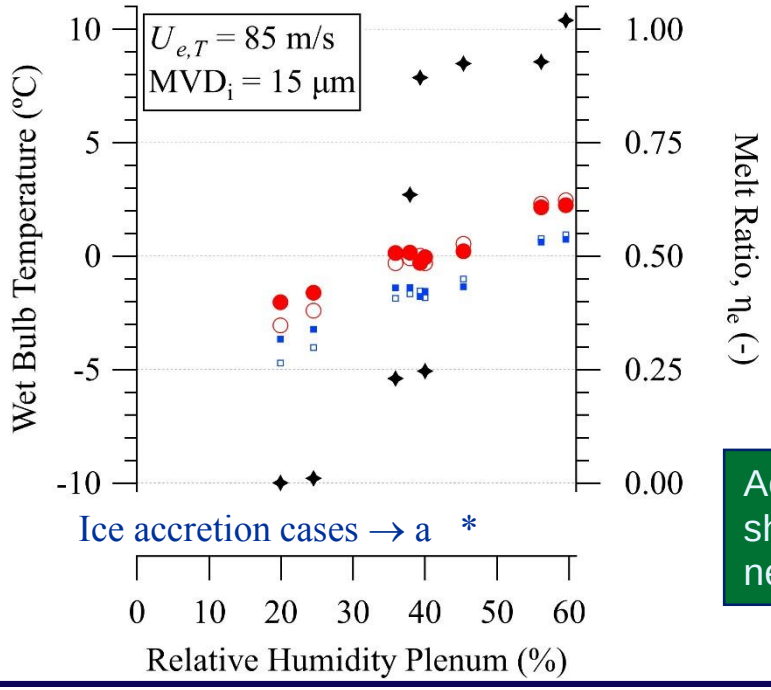
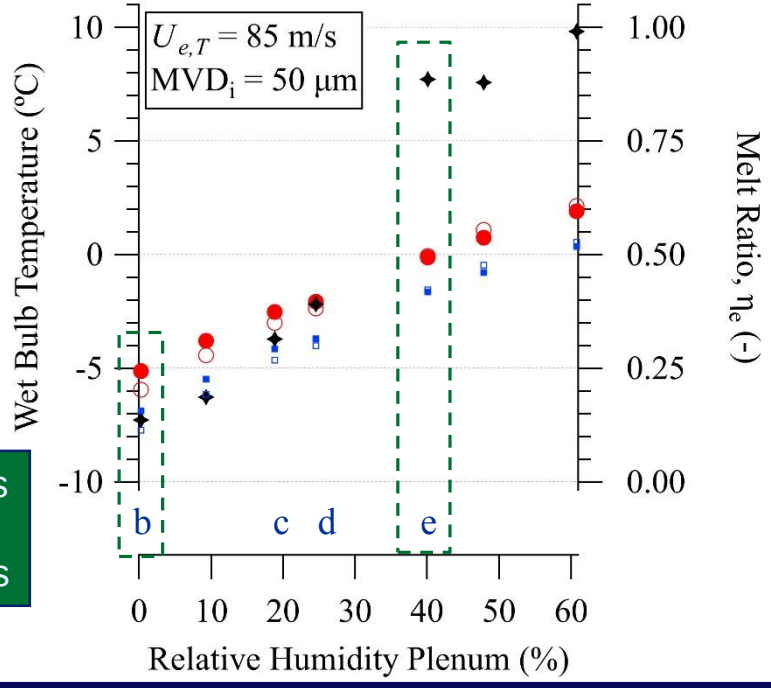




Accretions shown on next slides



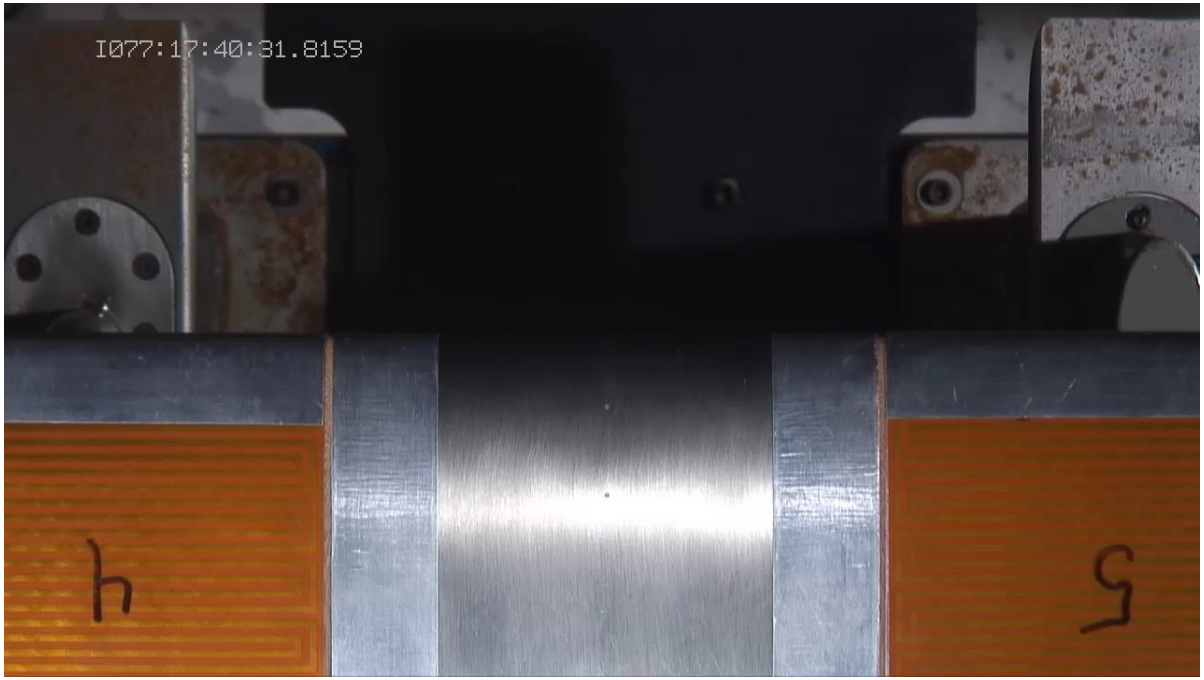
Ice Accretion Examples

Accretion “b”

Low melt ratio

8x actual speed

(10 minute spray time)



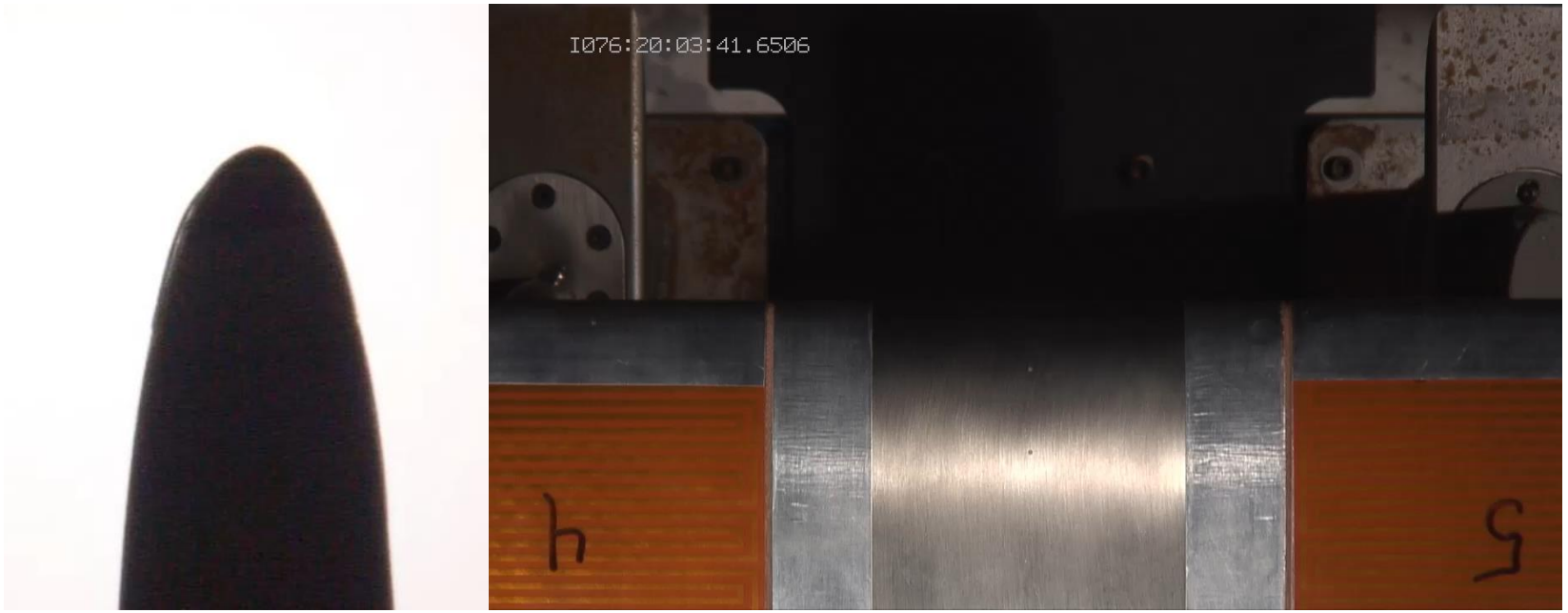
Ice Accretion Examples

Accretion “e”

High melt ratio

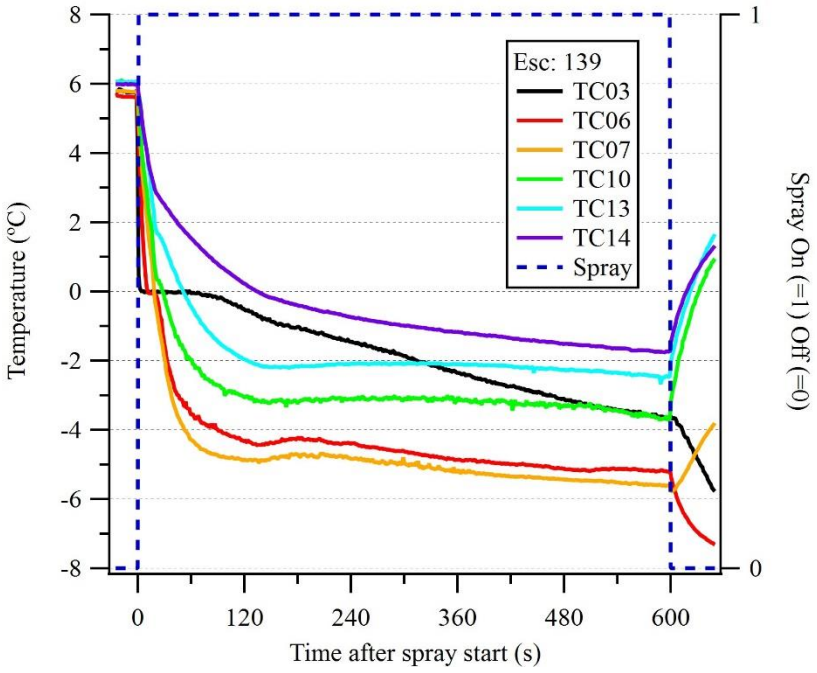
8x actual speed

(10 minute spray time)

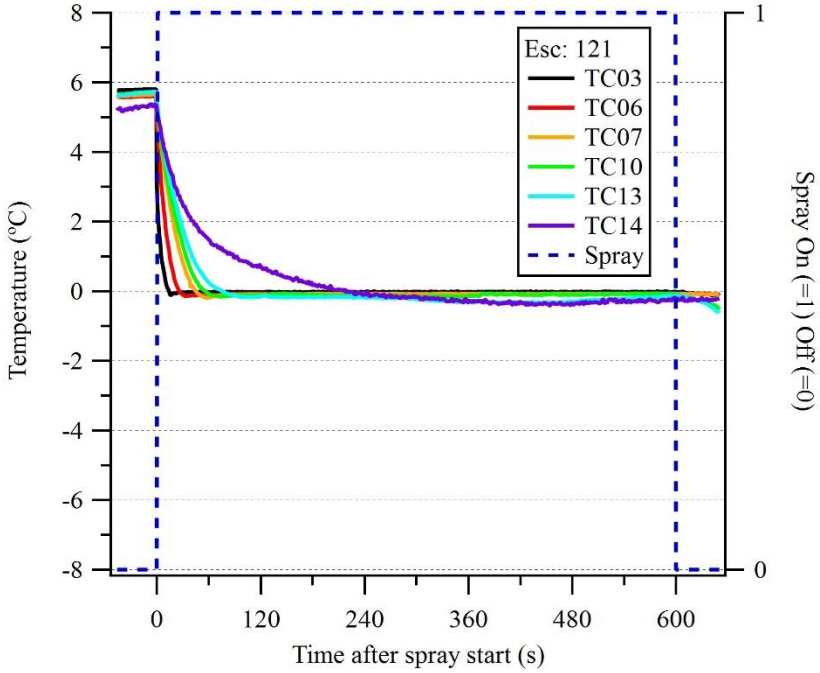


Surface TC meaurements

Accretion “b”
Low melt ratio



Accretion “e”
High melt ratio



Summary

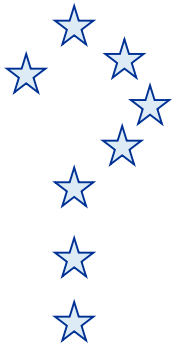
- NASA conducting research on fundamentals of ICI:
  - Identify and bound the conditions at the (local) accretion site
  - Generate & characterize conditions
  - Develop models & gather data on ice-crystal icing factors
- Generate environment outside of an engine to facilitate study
  - Using PSL as test bed
- Presented data from an 8-day test effort in March 2016, examining:
  - Freeze-out characteristics of cloud
  - Changes in aero-thermal conditions at the test section
  - Ice characteristics observed
- These result offer modelers a dataset to help develop and validate ice-crystal, mixed-phase accretion models.

Acknowledgement

- Financial support:
  - NASA's, Advanced Aircraft Icing (AAI) Subproject
    - Mr. Tony Nerone, Project Manager

- Special thanks to:
  - Staff of the NASA PSL
  - Mr. Chris Lynch for his excellent imaging work.

Questions



Backup Slides

Measurements

- Temperature
  - Rearward Facing Temperature Probe
  - Commercial TAT Sensor
- Humidity
  - Spectra sensor WVSS-II
- Pressure / velocity / Mach
- Uniformity
  - Traverse RTFP
    - Temperature
    - Humidity
  - Condensed phase water
    - PSL Tomography
- Total water content
  - Isokinetic Probe – version 2
- Liquid water content
  - SEA Multi-Element Probe
- Particle size distributions
  - Cloud Droplet Probe (CDP)
  - Cloud Imaging Probe (CIP)
  - High Speed Imager (HSI)
  - Phase Doppler Interferometer (PDI)
- Video cameras recorded ice accretion

Mixed-Phase Investigation

Plenum Relative Humidity Sweep Results

Test Section Changes is T and ω when cloud activiated

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